The Ecosystem Approach to Fisheries in the Mediterranean and Black Seas
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A trophic indicators toolbox for implementing an ecosystem approach in data-poor fisheries: the Algerian and Bou-Ismail Bay examples

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Summary: Over the past decade, the Algerian government has undertaken several incentives financed by state subsidies, via a range of development plans for fishing activities. Although these have led to the growth and modernization of the fishing fleet and the creation of various jobs, this increased fishing pressure has not maximized production as anticipated. In fact, catch is decreasing, and there are clear signs of stock overexploitation for several species, particularly sardines, for which catches have fallen dramatically. This study analyses the impact of fishing from an ecosystem perspective, with a view to the implementation of ecosystem approach to fishery management (EAFM) at the level of Algerian fisheries. To this end, a series of trophic indicators are used. The analysis shows that ecosystems at both national level and in the Bou-Ismail Bay are excessively exploited, and are altered by overexploitation and probably eutrophication. This situation is demonstrated in particular by the decrease in the average trophic level of catch, which is synonymous with "Fishing Down Marine Food Webs" (FDMW).

Keywords: trophic indicators; ecosystem approach to fisheries management; Algerian fisheries; data-poor fisheries; Bou-Ismail Bay.

Herramientas basadas en indicadores tróficos para la implementación del enfoque ecosistémico en pesquerías con escasez de datos: ejemplos de Argelia y Bahía Bou-Ismail

Resumen: Durante la década pasada, el gobierno argelino puso en marcha varios incentivos de financiación estatal, a través de una serie de planes de desarrollo para actividades pesqueras. A pesar de que este hecho ha originado crecimiento y modernización en la flota pesquera, además de la creación de puestos de trabajo, este aumento de la presión pesquera no ha permitido aumentar la producción pesquera como se había previsto. De hecho, las capturas están decreciendo y hay claros signos de sobreexplotación en varias especies, particularmente la sardina, para la cual las capturas han descendido drásticamente. Este estudio analiza el impacto de la pesca desde una perspectiva ecosistémica, con vistas a implementar el enfoque ecosistémico en la ordenación pesquera argelina. Se utilizan una serie de indicadores tróficos para este fin. El análisis muestra que los ecosistemas están muy explotados, alterados por la sobreexplotación y probablemente eutrofizados, tanto a nivel nacional como en la bahía de Bou-Ismail. Esta situación ha quedado demostrada concretamente por el descenso en el nivel trófico medio de las capturas, que significa la pesca de los niveles inferiores de la cadena trófica marina.

Palabras clave: indicadores tróficos; enfoque ecosistémico para la gestión pesquera; pesquerías argelinas; pesquerías con escasez de datos; bahía Bou-Ismail.

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INTRODUCTION

The FAO reported that in 2008, 85% of stocks were overexploited or fully exploited, and only 15% of stocks were underexploited or moderately exploited (FAO 2010). Furthermore, according to Worm et al. (2009), 63% of the world's evaluated fish stocks still need rebuilding, and lower exploitation rates are required to prevent stocks of vulnerable species from collapsing.

This situation of generalized overexploitation is accompanied by economic wastage and habitat degradation (FAO 2003, Pauly et al. 2000), revealing the relative failure of traditional fisheries management methods based on conventional approaches that essentially focus on species of commercial interest and examine each stock separately (Garcia et al. 2003, Cury et al. 2005a).

At its 19th session, held in March 1991, the FAO fisheries committee recommended those new approaches to fisheries management to be developed as a matter of urgency, taking into account conservation and environmental protection imperatives, as well as social and economic considerations (FAO 2003). This new management approach, known as the ecosystem approach to fisheries management (EAFM), is primarily based on the Code of Conduct for Responsible Fisheries (FAO 1995). The guidelines for its implementation were made official at the 2001 Reykjavík Conference on Responsible Fisheries in the Marine Ecosystem. All signatory countries (FAO 2001) accepted the final declaration of this conference, which stated that "In an effort to reinforce responsible and sustainable fisheries in the marine ecosystem, we will individually and collectively work on incorporating ecosystem considerations into that management."

However, the key problem lies in the practical application of the EAFM's politically and ethically correct instructions and suggestions (Garcia and Cochrane 2005). Moreover, it is difficult to define operational objectives, reference points and performance indicators for the ecosystem approach (Morishita 2008) in the absence of data on the original unexploited situations for use as recovery objectives (Gislason et al. 2000).

The major challenge in integrating ecosystem considerations into fisheries management is the definition of measurable indicators which take into account impacts on both the structure (biodiversity) and function (habitat productivity) of marine ecosystems (Gislason et al. 2000). To be useful, ecosystem indicators should be sensitive to differences in the integrity of ecosystems between places and over time. They should also be easily measurable, understandable, informative, based on accessible data, and able to integrate uncertainty (Link 2002).

Pauly et al. (1998) used the mean trophic level (MTL) of world catches between 1950 and 1994 from the FAO database to evaluate the sustainability of exploitation systems used throughout the world. The study showed that the trophic level of landings decreased gradually over time, and that fisheries progressively moved away from long-lived species from high trophic levels and benthic piscivores towards short-lived species, invertebrates and planktivorous pelagic fish (Pauly et al. 1998). This phenomenon, known as "Fishing Down Marine Food Webs" (FDMW), currently studied using the marine trophic index (MTI), which is the Commission for Biological Diversity's name (CBD 2004) for the MTL, has now been observed in several regions of the world: in Thailand (Christensen 1998), Canada (Pauly et al. 2001), Greece (Stergiou and Koulouris 2000), the common Argentine-Uruguayan fishing zone (Jaureguizar and Milessi 2008), Brasil (Freire and Pauly 2010), the Mediterranean and the Black Sea (Pennino et al. 2011), and elsewhere.

However, the use of the MTI alone to show FDMW has been criticized by Caddy et al. (1998). Criticisms include the fact that fishing towards the bottom of the trophic chain can be a conscious choice, and that the "bottom-up" phenomenon (an increase in primary production) in coastal zones and in semi-enclosed seas lowers the average trophic level of catch. These criticisms have led to the development of other indicators, which are currently used together to evaluate the state of ecosystems exploited by fishing. These include the "fishing-in-balance" (FiB) index developed by Pauly et al. (2000) to analyse (among other things) the expansion and contraction of fisheries, and the "^{cut}marine trophic index" (^{cut}MTI) (Pauly and Watson 2005), which deals with abundance changes for species at intermediate and upper trophic levels, and with the evaluation of FDMW in the coastal systems of semi-enclosed seas. These indicators, along with the ratio of pelagic and demersal fish landings (P/D) (Caddy 2000), are easily obtained from generally available and accessible data on commercial fisheries landings. They are therefore perfectly suited for studying fisheries such us the Algerian ones for which few data are available.

In the present paper we develop a set of the aforementioned indicators with a combination of statistical techniques such as smoothing techniques and bootstrapping to assess the ecological balance of the Algerian marine ecosystem. First, we analyse fishery data collected in the Bou-Ismail Bay from 1999 to 2012 to obtain an accurate local spatial approach. Then we extend the analyses to all landings from 1999 to 2010 in order to study the fishery exploitation within an ecosystem perspective. Finally, we explore how environmental conditions, such as sea surface temperature (SST), chlorophyll-*a* and rainfall concentrations can contribute to different levels of catch.

MATERIALS AND METHODS

Study area

The Bou-Ismail Bay (Algeria) is in the Algerian sub-basin of the western Mediterranean between 2°54'E 36°48'N and 2°24'E 36°38'N. It is considered to be one of the most important bays on the Algerian coast regarding fisheries production. It has three fishing ports: Tipasa, Khemisti and Bouharoun. The ports of Khemisti and Bouharoun are the most important in the area in terms of fleet concentration and quantities

landed. There is also a mooring beach (Fouka) and a converted fishing shelter (Bou-Ismail). As of December 2012, the fishing fleet in the ports of Bouharoun and Khemisti consists of 307 units, including 27 trawlers, 108 sardine boats and 172 small traders. The vessel concentration is higher at the port of Bouharoun (73%). There are also a few yachtsmen at Khemisti and two tuna boats registered at Bouharoun.

The data

Catch and fleet data

The 1999-2012 catch and fleet data for the Bou-Ismail Bay were collected by the Fisheries and Marine Resources Directorate (Direction de la Pêche et des Ressources Halieutiques, or DPRH) of the *wilaya* (province) of Tipasa, which is the authority in charge of fishing in this zone. Catch data concern all the landings by the fleet's four segments (trawlers, sardine boats, small traders and yachtsmen) for the bay's two main ports (Bouharoun and Khemisti).

The total annual catch data for 1999 to 2010 are from the General Fisheries Commission for the Mediterranean (GFCM) database, on the website http://www.fao.org/fishery/statistics/GFCM-capture-production/query/en. The data on the Algerian national fleet are from the website of the Ministère de la Pêche et des Ressources Halieutiques (MPRH) (http://www.mpeche.gov.dz).

The environmental data

For ocean processes, chlorophyll-*a* (Chl-*a*) concentration and SST data can be used to locate thermal and productivity-enhancing fronts and marine productivity hotspots and thus determine the influence of such features on species distribution. In addition, SST and Chl-*a* are also strong functional links between surface primary productivity and biological activity at the sea floor through the episodic deposition of particulate material (Aminot and Chaussepied 1983).

The environmental satellite (SST and Chl-*a*) data were extracted as a monthly mean from the Environmental Marine Information System (EMIS) online platform (http://emis.jrc.ec.europa.eu/), using two sensors, SeaWiFS (January 1999-Decembrer 2003) and MODIS-A (January 2004-December 2012), at a resolution of 4 km.

In addition, in order to assess nutrient input in the ecosystem, we analysed rainfall data (*mm/h*). The monthly means were obtained using the "Time series" function at the web platform GIOVANNI (http://disc.sci.gsfc.nasa.gov/giovanni) at a resolution of 1 km.

The trophic levels of landed species

Trophic indicators are highly sensitive to the trophic level (TL) attributed to landed species. The difficulty of attributing TLs to landed species lies in the fact that most catches are assigned to species groups that above all concern landings statistics for the Bou-Ismail Bay. Pauly et al. (1998) emphasized this problem by analysing the global catch data from the FAO database in terms of TLs. Consequently, the database was first disaggregated into taxonomic species based on FishBase and certain documents dealing with fauna surveys on the Algerian coasts, primarily Massuti et al. (2004), PNUE (2005), Hemida (2005) and Refés et al. (2010). The TL and the standard error for each species were then assigned according to FishBase (www.fishbase.org), or in some cases according to Stergiou and Karpouzi (2002) for fish, and SeaLifeBase (www.sealifebase.org) for molluscs and crustaceans. These TLs were estimated, mostly based on the species' diets (Table 1 and 2).

The TLs for giant red shrimp (*Aristaeomorpha foliacea*) and common shrimp (*Melicertus kerathurus*) were unavailable. To these two species, we have attributed the TLs of the blue and red shrimp (*Aristeus antennatus*) and the deep-water rose shrimp (*Parapenaeus longirostris*), respectively. It should be noted that the "other osteichthyes" group in the GFCM database was not included in the calculation of trophic indicators because it was impossible to attribute a TL to this group.

The ecosystem indicators used

Pelagic/demersal ratio

The pelagic/demersal (P/D) ratio is defined as the ratio of pelagic species landings to demersal species landings (in weight). Eutrophication and/or overexploitation are the key phenomena that can influence the trend for this ratio (Caddy 1993, 2000, De Leiva Moreno et al. 2000, Libralato et al. 2004, Pennino and Bellido 2012). In fact, pelagic species (mainly small pelagic planktivores) are positively affected by the increase in nutrients which stimulate primary production (Caddy 1993), whereas demersal species are negatively affected by the hypoxia arising from the excess of primary production. Consequently, the P/D ratio indirectly indicates nutrient availability levels (De Leiva Moreno et al. 2000).

The P/D ratio is also useful for studying the overall evolution of the fishery. In fact, a high demand for demersal fish and an increase in the P/D ratio can be explained by an overexploitation of demersal species (Pennino and Bellido 2012). Moreover, like other catch-based indicators, it is sensitive to the evolution of target species and fishing methods (Pennino et al. 2011). As a result, this ratio is compared with landings for certain species groups that are important to the fishery and to the evolution of the fishing fleet.

The influence of eutrophication on the fishery and the ecosystem is analysed by comparing the P/D ratio with certain environmental parameters, namely Chl-*a* and SST, which are indicators of primary production, and precipitation, which causes soil runoff.

In this study, species are classified as pelagic or demersal according to FishBase (see Table 3). When calculating the P/D ratio, we only consider small, mainly planktivorous fish like Clupeidae (sardines

Table 1. – The trophic levels (TL) with their corresponding standard errors (se) and average annual catches (C) in tonnes for species or groups of species landed between 1999 and 2012 in the Bou-Ismail Bay.

Species	TL	se	C	Species	TL	se	C
Demersal fish				Small pelagics			
Mullus spp.	3.30	0.45	138.01	*Sardinella* spp.	3.13	0.33	891.10
Boops boops	3.30	0.47	228.02	*Engraulis encrasicolus*	3.10	0.45	39.06
Pagellus erythrinus	3.53	0.52	157.20	*Sardina pilchardus*	3.10	0.20	3781.57
Spicara spp.	3.60	0.35	0.11	*Trachurus* spp.	3.50	0.47	628.97
Sparus aurata	3.30	0.50	1.73	*Scomberi* spp.	3.40	0.50	33.60
Dentex dentex	4.30	0.65	0.01	Clupeoidei	3.33	0.43	18.47
Pagrus spp.	3.55	0.55	8.39	Large pelagics			
Diplodus sargo	3.05	0.34	0.69	*Auxis thazard* and *A. rochei*	4.10	0.60	0.01
Oblada melanura	3.00	0.10	0.27	*Seriola dumerili*	4.50	0.80	5.98
Micromesistius poutassou	4.00	0.70	23.97	*Sphyraena* spp.	4.00	0.51	8.97
Merluccius merluccius	4.40	0.80	0.38	*Sarda sarda*	4.15	0.65	9.97
Epinephelus spp.	3.90	0.60	1.21	*Xiphias gladius*	4.50	0.60	66.60
Soleidae	3.26	0.41	11.04	*Thunnus thynnus*	4.35	0.75	5.60
Pleuronectidae	4.00	0.65	0.03	*Euthynnus alletteratus* and *Orcynopsis unicolor*	4.50	0.80	0.90
Scophthalmidae	3.97	0.72	0.08	Pelagic sharks	4.18	0.62	13.04
Scorpaenidae	3.88	0.62	0.33	Various bony fish	4.21	0.63	0.27
Phycis spp.	4.00	0.65	0.01	Crustaceans			
Triglidae	3.55	0.52	0.18	*Aristeus antennatus*	3.30	0.47	55.19
Sarpa salpa	2.00	0.00	2.14	*Aristaeomorpha foliacea*	3.30	0.47	3.64
Liza aurata	2.50	0.20	0.07	*Parapenaeus longirostris*	3.30	0.44	95.18
Dicentrarchus labrax	3.80	0.60	1.27	*Crangon crangon*	3.30	0.44	2.03
Argyrosomus regius	4.30	0.75	0.01	*Palinurus* spp.	3.34	0.66	0.20
Conger conger	3.93	0.70	0.06	*Nephrops norvegicus*	2.83	0.31	0.01
Muraena helena	3.80	0.60	0.14	Crustacea	3.19	0.47	2.12
Torpedo spp.	4.50	0.80	0.96	Molluscs			
Rajiformes	3.79	0.56	9.66	Octopodidae	3.65	0.64	26.75
Myliobatiformes	4.16	0.55	0.01	*Loligo* spp.	4.06	0.77	8.66
Scyliorhinus spp.	3.70	0.60	0.06	*Sepia officinalis*	3.56	0.56	19.38
Squalus acanthias	4.00	0.50	0.09	Various molluscs	3.77	0.67	10.33
Elasmobranchii	3.68	0.54	77.51				

Table 2. – The trophic levels (TL) with their relative standard errors (se) and average annual catches (C) in tonnes for species or groups of species landed between 1999 and 2010, at national level.

Species	TL	se	C	Species	TL	se	C
Solea solea	3.10	0.30	274	Clupeoidei	3.11	0.33	1727.6
Merluccius merluccius	4.40	0.80	488	*Engraulis encrasicolus*	3.10	0.45	2806
Phycis blennoides	3.70	0.60	29.2	*Sardina pilchardus*	3.10	0.20	60306
Boops boops	3.30	0.47	5605	*Sardinella* spp.	3.13	0.33	21032
Pagellus erythrinus	3.40	0.50	1227	*Trachurus* spp.	3.50	0.47	13466
Dicentrarchus labrax	3.80	0.60	19	*Scomber scombrus*	3.70	0.60	1322.2
Trachinus draco	4.20	0.71	2	*Sphyraena* spp.	4.15	0.66	360.75
Epinephelus spp.	3.83	0.58	69.8	*Seriola dumerili*	4.50	0.80	306.33
Serranidae	3.82	0.59	0.5	*Thunnus thynnus*	4.40	0.80	1245
Mugilidae	2.50	0.20	110	*Sarda sarda*	4.50	0.70	706
Pagrus spp.	3.70	0.60	322	*Auxis thazard* and *A. rochei*	4.20	0.65	550.5
Sparidae	3.10	0.35	0.58	*Euthynnus alletteratus*	4.50	0.80	213.83
Pagrus pagrus	3.70	0.60	141	*Orcynopsis unicolor*	4.50	0.80	54.833
Oblada melanura	3.00	0.10	6.83	*Katsuwonus pelamis*	3.80	0.60	17.417
Sarpa salpa	2.00	0.00	36	*Xiphias gladius*	4.50	0.60	706.83
Lithognathus mormyrus	3.40	0.50	4.08	*Aristeus antennatus*	3.30	0.47	1020.4
Mullus spp.	3.30	0.45	1659	*Palaemon serratus*	2.69	0.32	0.75
Diplodus sargus	3.00	0.30	15.1	*Crangon crangon*	3.23	0.40	3.3333
Conger conger	4.30	0.80	6.25	*Parapenaeus longirostris*	3.30	0.44	1317.3
Zeus faber	4.50	0.80	0.42	Crustacea	3.12	0.43	93.75
Lophius spp.	4.50	0.80	35.3	*Nephrops norvegicus*	2.83	0.31	66.5
Scorpaenidae	3.72	0.57	77.8	*Palinurus* spp.	3.34	0.66	63.833
Scyliorhinus spp.	3.85	0.55	41.5	Cephalopoda	3.77	0.68	93.75
Squalidae	4.15	0.65	26.3	*Sepia officinalis*	3.56	0.56	356.67
Squalus acanthias	4.30	0.70	4	*Loligo* spp.	4.10	0.85	209.58
Rajiformes	3.79	0.56	339	Mollusca	3.77	0.68	13.5
Elasmobranchii	4.10	0.61	217	Octopodidae	3.65	0.64	646.5

and sardinellas) and Engraulidae (anchovies) as pelagic. Mid-sized pelagics (jack and horse mackerels, *Trachurus* spp., and mackerels, *Scomber* spp.) are not included in the analysis, because their diet includes small pelagic fish and squid as well as plankton (De Leiva Moreno et al. 2000). The same applies to golden grey mullet (*Lisa aurata*), which is a catadromous species, and to unidentified fish (*Marine fishes nei*) on the MPRH database, given that they cannot be considered pelagic or demersal.

Marine trophic index

The MTI is one of the eight indicators identified at the February 2004 Convention on Biological Diversity CBD) by the Conference of the Parties for use

in evaluating progress in the slowing of biodiversity reduction (CBD 2004). It was developed as part of the UBC Fisheries Centre's (www.fisheries.ubc.ca) project (www.seaaroundus.org), and was introduced in order to examine the impact of fisheries on the world's marine ecosystems. The MTI is calculated for each year *k* using the following formula:

$$MTI_k = \sum_i (TL_i)(Y_i) \Big/ \sum_i Y_i$$

where MTI is the mean trophic level of landings for the year *k*, Y_i represents landings of the trophic group *i*, and TL is the trophic level of the species or trophic group *i*.

The ^{cut}marine trophic index

The eutrophication phenomenon in coastal zones and semi-enclosed seas (caused by runoff waters and anthropogenic inputs) increases primary production and therefore the abundance of planktivorous species, which lower the mean TL of catch, creating confusion with FDMW (Caddy et al. 1998). One particularly illustrative example is the Peruvian anchoveta (*Engraulis ringens*). Massive catches of this species heavily influence the TL of overall catches (Pauly et al. 1998).

To avoid this problem, Pauly and Watson (2004) have suggested that all low-TL species should be excluded from the calculation, producing a new indicator known as the ^{cut}MTI. This indicator is calculated by excluding all species belonging to TLs below 3.25, such as herbivores, detritivores and planktivores, which exhibit significant fluctuations in response to environmental conditions.

Fishing-in-balance index

Pauly et al. (2000) revealed a problem with using the decrease in the mean TL of landings as proof of a given fishery's impact on the ecosystem. Thus, in order to correctly evaluate the impact of fishing, the assessment should not be based uniquely on an index that decreases when the fishery is oriented towards the bottom of the trophic chain for a given ecosystem (Pauly et al. 2000).

Moreover, marine ecosystems function like pyramids in which the primary production generated at (TL=1) is displaced upwards to the TL above with a considerable rate of loss, when used in the maintenance processes, reproduction and other activities of the animals within the systems (Pauly and Christensen 1995). Inversely, biological production increases by a factor of ten with a downward move of just one level (Pauly et al. 2000). Consequently, displacement towards the bottom of the food chain can be the result of a conscious choice, given that biological production is higher at lower TLs (Pauly et al. 2000, Pauly and Watson 2005).

To avoid these production losses, a decrease in the average TL of catches should be compensated by an appropriate ecological increase of these catches (in biomass terms). This increase is determined by the transfer efficiency (TE) between TLs (Pauly and Watson 2005). Thus, Pauly et al. (2000) proposed the FiB index, including the notion of TE and making it possible to evaluate whether or not a fishery is balanced in ecological terms. The FiB index for the year *i* of a historical series is defined by the equation

$$FiB = \log\left[Y_i\left(\frac{1}{TE}\right)^{TL_i}\right] - \log\left[Y_0\left(\frac{1}{TE}\right)^{TL_0}\right]$$

where Y represents catch, TE is the transfer coefficient (0.1, according to Pauly and Christensen 1995), and 0 is the base year (1999 for the purposes of this study).

Pauly and Watson (2005) define the evolution of FiB as follows:

it remains constant (FiB=0) if the changes in TL are compensated by "ecologically correct" changes in catches;

it increases (FiB>0) if there is a "bottom-up" effect (a geographical expansion of fishing, and exploitation of a wider ecosystem);

it decreases (FiB<0) if discards are not taken into account in catches, or if the fishery removes so much biomass from the ecosystem that its operation is altered.

Statistical analysis

The statistical analysis was conducted using the R software (R Development Core Team 2013). To evalu-

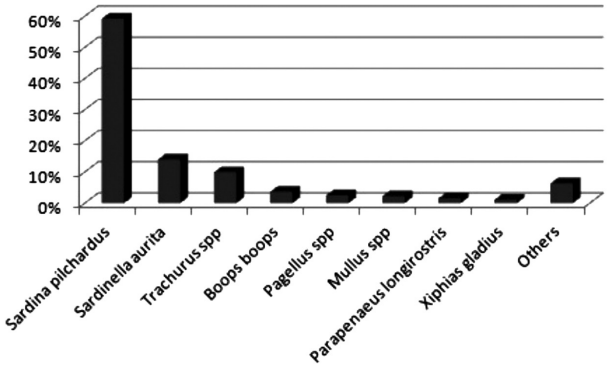

Fig. 1. – Species composition of landings in the Bou-Ismail Bay (only species for which the average catch is equal to or above 1% are shown: the other species or species groups for which catches below 1% are collectively accounted for as "Others").

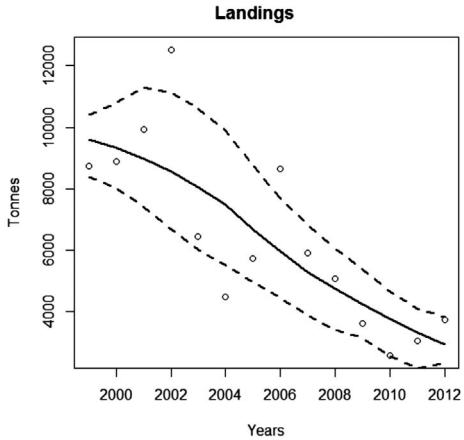

Fig. 2. – Landings in the Bou-Ismail Bay from 1999 to 2012. The continuous line represents the fit of the landings and the dotted lines show the 95% confidence bands. Locally-weighted regression and bootstrapping was used to obtain the smoothing curve and confidence intervals.

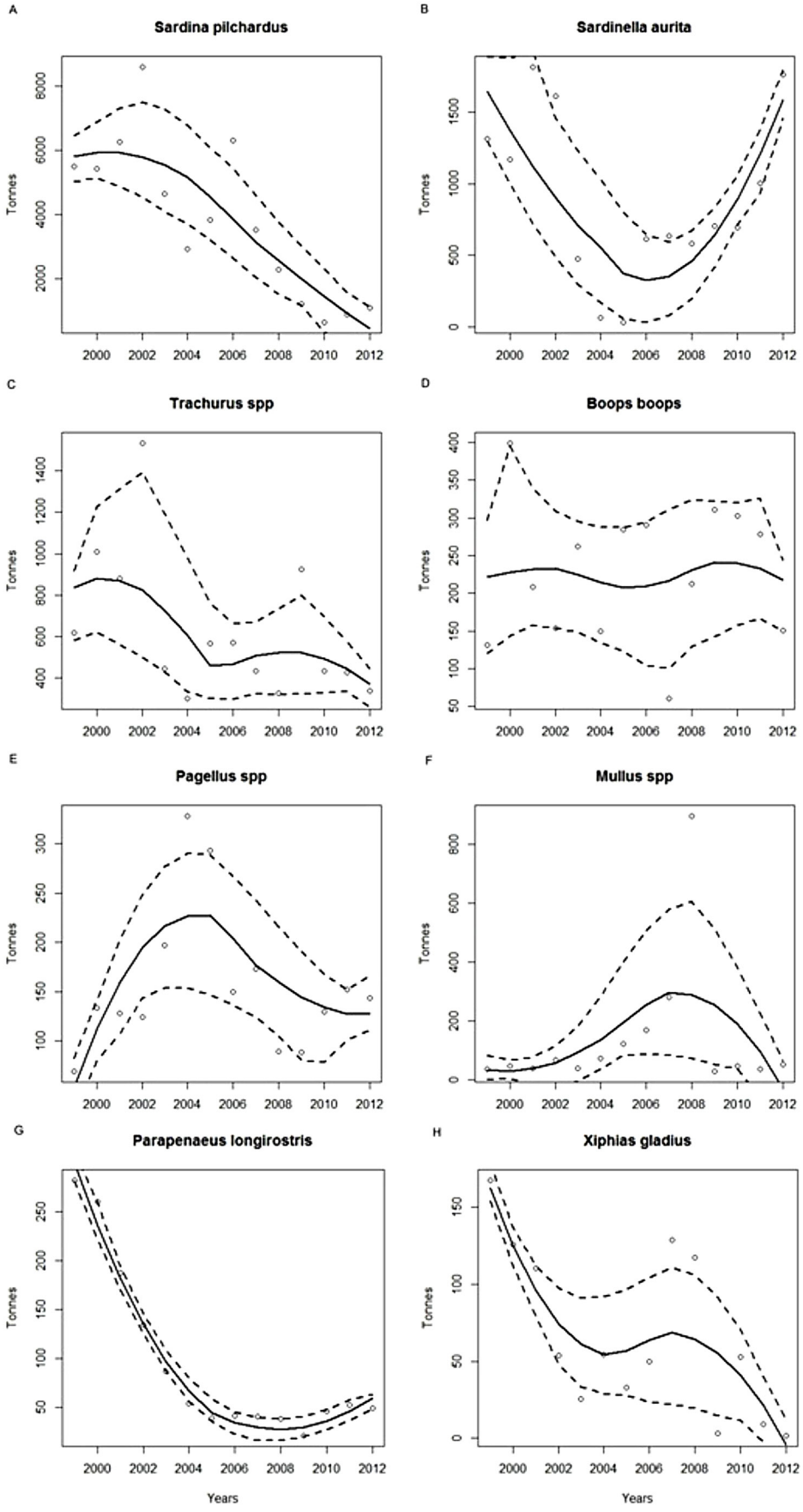

Fig. 3. – Landings of the main species caught in the Bou-Ismail Bay from 1999 to 2012.

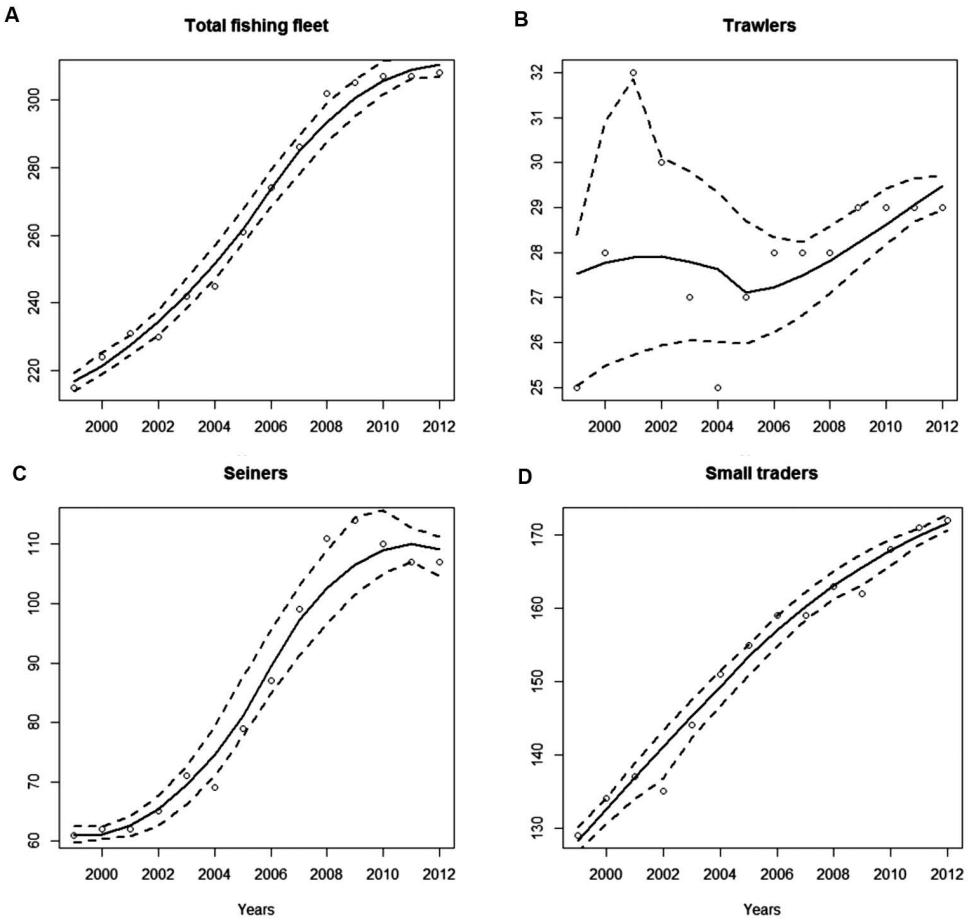

Fig. 4. – Total fishing fleet (A), trawlers (B), sardine boats (C) and small traders (D) working in the Bou-Ismail Bay between 1999 and 2012.

ate the statistical variability of the parameters studied, we used the *bootstrap* method (Efron 1979). For curve fitting, we applied the "Loess" locally-weighted regression method (Cleveland 1979), with a smoothing factor (span =1). A confidence interval of 95% obtained from 1000 *bootstrap* replicas was calculated for the Loess smoothing (see Pennino et al. 2011 for more information).

RESULTS

The Bou-Ismail Bay

The species composition of landings (Fig. 1) shows the dominance of sardines (*Sardina pilchardus*), constituting over 59% of landings, followed by round sardinella (*Sardinella aurita*), at around 14% of catch. These two small pelagic species make up 73% of the Bou-Ismail Bay fishery's average annual fishing production.

The total annual landings (Fig. 2) declined constantly during the years studied, falling from over 8000 t to less than 4000 t: a decrease of over 50%. This significant fall in fishing production is due to the decline in sardine catch (Fig. 3), which fell from over 5000 t to around 1000 t between 1999 and 2012. Other species showing declining production included jack and horse mackerels (*Trachurus* spp.), (Fig. 3), deep-water rose shrimp (*Parapenaeus longirostris*) and swordfish (*Xiphias gladius*). In contrast, round sardinella (*Sardinella aurita*) and the principal demersal fish, namely bogue (*Boops boops*), pagellus (*Pagellus* spp.) and red mullets (*Mullus* spp.), alternated between periods of rising and falling catch (Fig. 3).

The total fishing fleet (Fig. 4A) increased significantly during the years considered, from 215 units in 1999 to 308 units in 2012: an increase of 93 units with a 43% rate. The significant increases were for sardine boats (Fig. 4C) and small traders (Fig. 4D), 46 and 43 additional units respectively, with respective rates of 75% and 33%. Trawler numbers (Fig. 4B) barely changed: from 24 units in 1999 to 29 units in 2012.

The fishing fleet includes boats from Tipasa province, with Bouharoun and Khemisti as landing ports. However, although an official census of fishing boats exists, it is very difficult to define the fishing effort exerted on marine resources in the Bou-Ismail Bay. Indeed, the number of the fleet registered is not truly representative of the real fleet operating in the bay. Several registered vessels are not operational (wrecks, missing boats, etc.) and there is also a significant movement of vessels between fishing grounds of the Algerian coast that is difficult to monitor. Due to this lack of finer data, our main interest is to study the trend of the fishing fleet and how it evolves throughout the study period, and how this can affect the ecosystem.

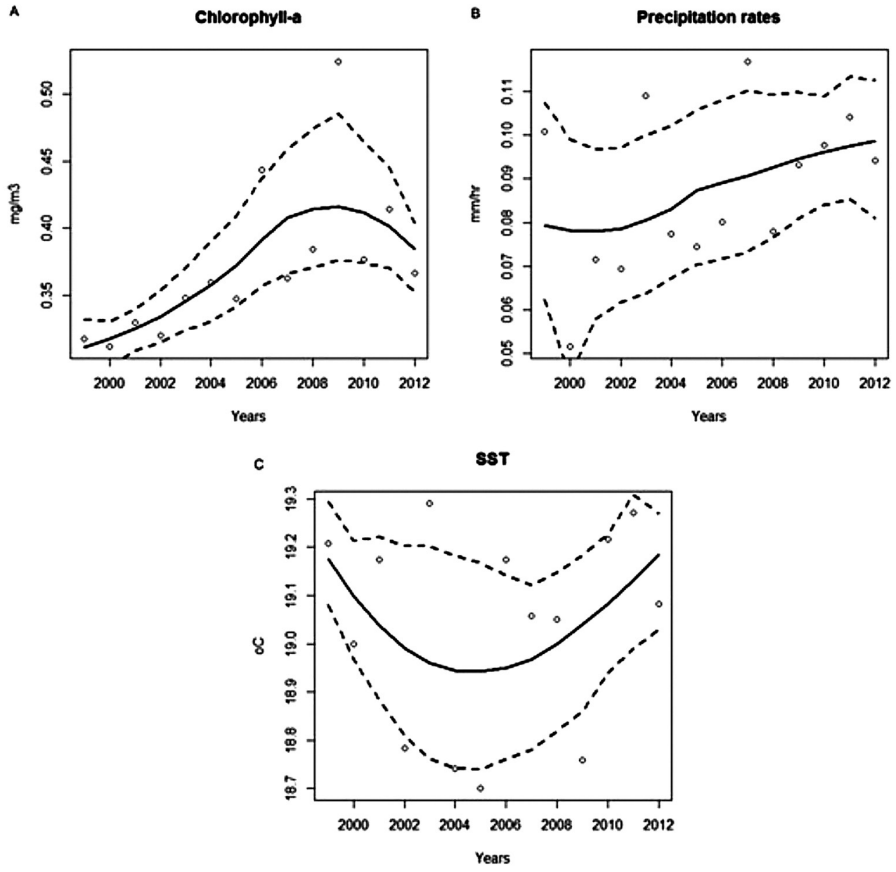

Fig. 5. – Chlorophyll-*a* concentration (A), precipitation rates (B) and sea surface temperature (C) in the Bou-Ismail Bay from 1999 to 2012.

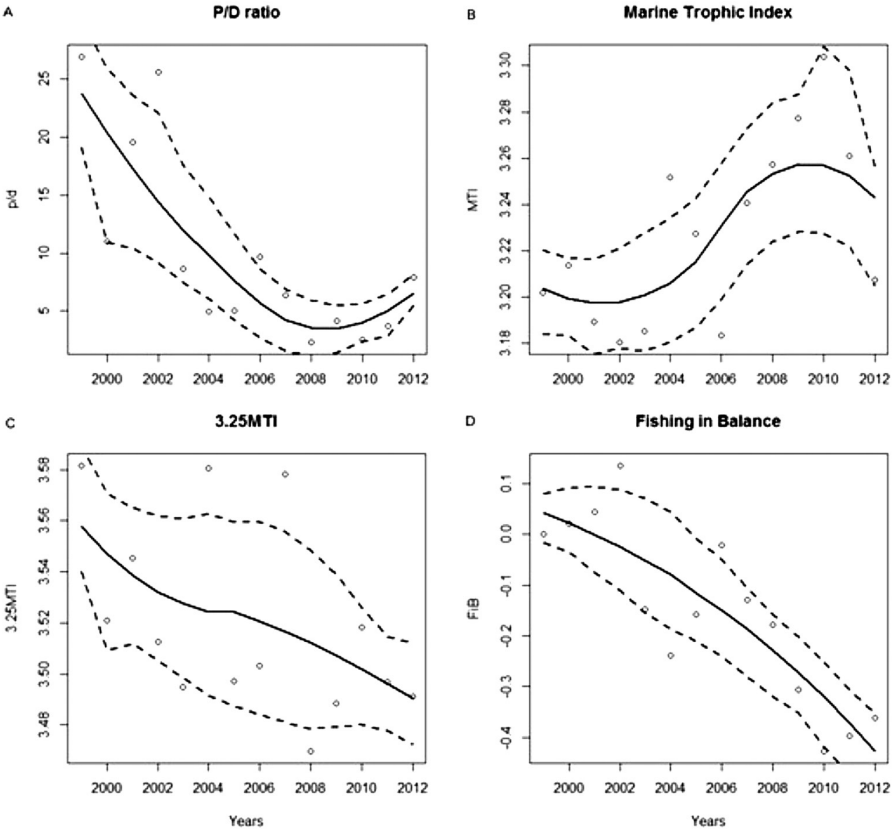

Fig. 6. – Trophic indicators for catches in the Bou-Ismail Bay from 1999 to 2012.

Regarding the environmental variables, Chl-*a* (Fig. 5A) increased until 2008, peaking at 0.41 cmg/m^3. It then decreased slightly while precipitation levels rose constantly during the period considered, from 692 mm (0.08 mm/h) in 1999 to around 858 mm (0.1 mm/h) in 2012 (Fig. 5B). The SST exhibited a gradual increase from 2007 in Algerian waters, reaching the maximum value of 19.27°C in 2012 (Fig. 5C).

Among the trophic indicators, after reaching 24 in 1999, the P/D index (Fig. 6A) decreased slightly until 2008, to a low of 3.5. A slight increase then began. The annual average calculated for the period in question is estimated at 9.9.

The average MTI for the series in question is estimated at around 3.23. During the first six years, the values for the MTI (Fig. 6B) were at their lowest for the period in question (~3.2). This coincided with high catches of sardines (*Sardina pilchardus*) from a low TL of 3.1. Subsequently, the MTI rose, whereas sardine catch continued to fall. MTI values were at their highest during the last years, reaching a peak of 3.26 in 2009 and coinciding with the lowest sardine catches. However, at the very end of the series, the MTI began to fall. This trend explains the high catches of round sardinella (*Sardinella aurita*) with a low TL (TL=3.13). In fact, this species became the dominant species in landings from 2009, constituting almost 47% of overall catch in 2012, and exceeding sardine catch (Fig. 7).

If species of TL<3.25 (salema, golden grey mullet, Norway lobster, saddled seabream, sargo bream, anchovy, sardine, round sardinella and various crustaceans) are excluded from the calculation, the average TL of catch ($^{3.25}$MTI) from 1999 to 2012 is estimated at 3.52. It is very close to that of jack and horse mackerels (*Trachurus* spp.) and pagellus (*Pagellus* spp.). The $^{3.25}$MTI (Fig. 6C) fell throughout the period studied. It decreased from 3.56 in 1999 to 3.49 in the final year of the series. This decrease of TLs by 0.07 over the 14 years studied is mainly due to the jack and horse mackerel catch declining by over 50%. In fact, if sardine and round sardinella catches are removed from the calculation, jack and horse mackerel, of medium TL (TL=3.5), become dominant, consequently impacting considerably on the $^{3.25}$MTI trend. The increase in *Pagellus* spp., (TL=0.53) catch during the early years did not alleviate the effects of falling catches of jack and horse mackerel and swordfish (*Xiphias gladius*), of TL 4.5. From 2005, catches fell for all of the fishery's major low- and medium-TL species, accentuating the fall in $^{3.25}$MTI to its lowest values in the series.

The FiB shows a clear declining trend during the period in question, with negative values from 2002 onwards (Fig. 6D). In fact, a value of 0.05 was recorded in 1999, and a value of -0.45 was recorded in 2012. This decrease was accompanied by a decrease in overall catch.

At national level

The average national fishing production is estimated at 126300.5 tonnes. Like the Bou-Ismail fishery, it is dominated by small pelagics, mostly sardine (*Sardina pilchardus*) at 46% of total landings, followed by round sardinella (*Sardinella aurita*) at 17%, and jack and horse mackerels (*Trachurus* spp.) at 11% (Fig. 8). National landings (Fig. 9A) increased to a peak of 138483 in 2006, before falling. This trend coincides with that seen for small pelagic species catches (Fig. 9B). The proportion of these species in landings (80%) clearly influences overall catch. Demersal species (Fig. 9C), molluscs (Fig. 9F) and (to varying degrees) large pelagics (Fig. 9D) contributed to the rise in overall landings during the early years. However, the continuing rise in demersals did not counterbalance the declining trend for total catch during the last few years. Crustaceans (Fig. 9E) fell by around 1000 tonnes until 2007, before catch began to rise again. Among the trophic indicators, after rising slightly from 1999 to 2004, the P/D index fell significantly, reaching its lowest value of around 5 at the end of the series (Fig. 10A). The MTI fell from 3.25 to 3.22 between 1999 and 2003 (Fig. 10B) and then rose, reaching 0.07TL in 2010. The $^{3.25}$MTI fell by around 0.1TL between 1999 and 2007 (Fig. 10C). Following this, it entered a rising trend because of a significant demersal species catch in the later years. The FiB values were positive during the whole period studied, except in the last year, when a value of –0.16 was recorded (Fig. 10D). In fact, following a period of increase with a peak of 0.13 in 2006, the FiB fell, reaching a low of –0.16 in the last year of the series. The trends for landings and the FiB index coincide. The rise in the FiB is accompanied by the rise in overall catch and vice versa.

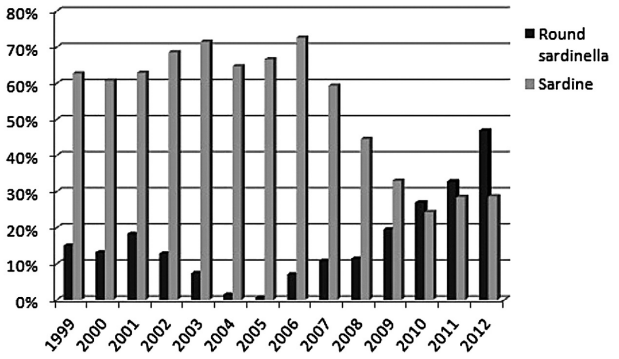

Fig. 7. – Sardine and round sardinella catch levels in the Bou-Ismail Bay from 1999 to 2012.

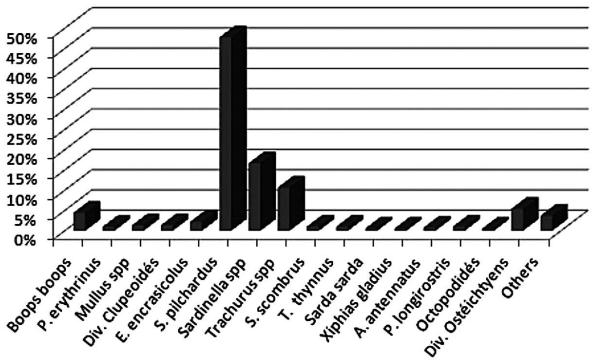

Fig. 8. – Species composition of landings at national level.

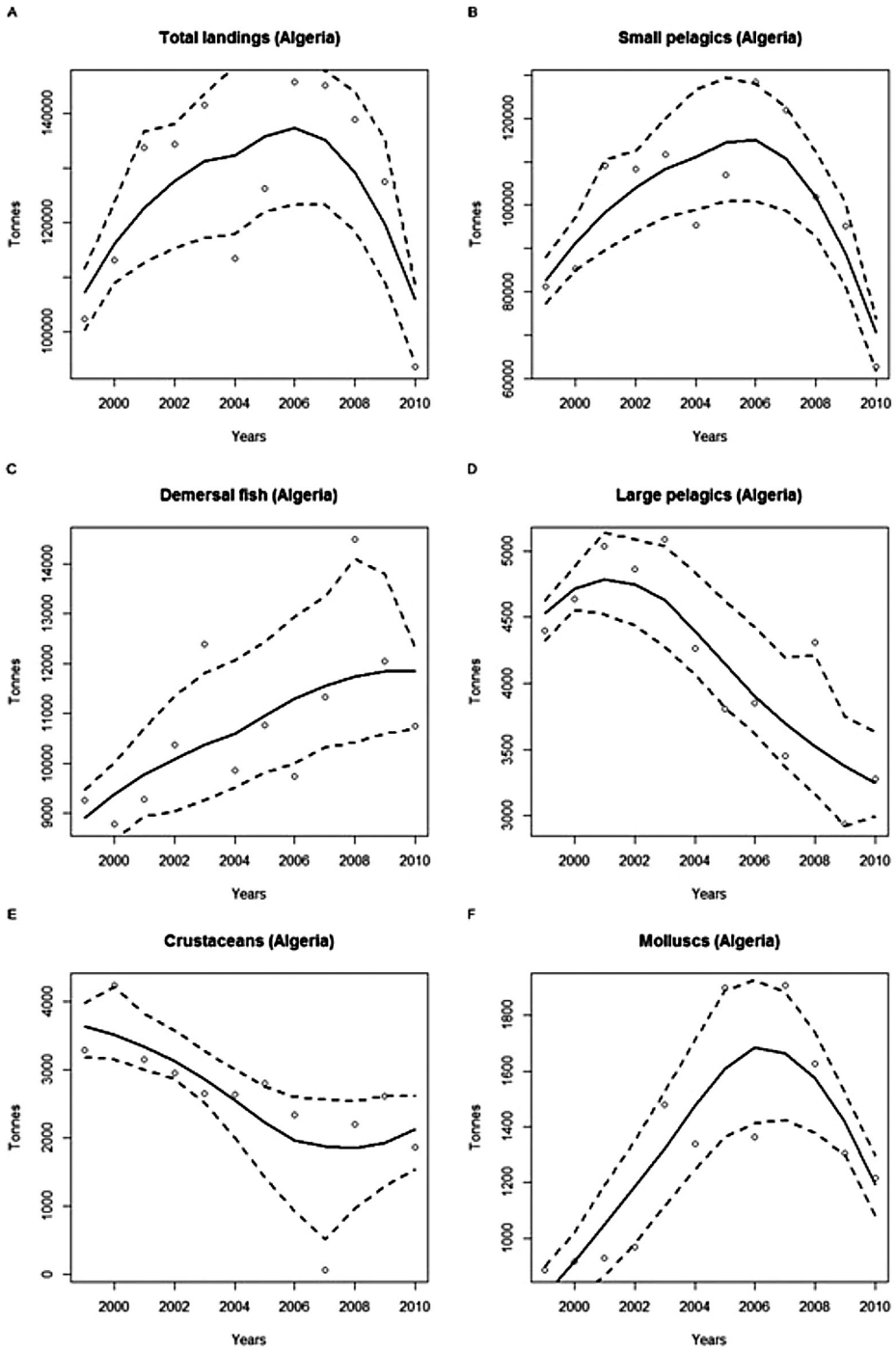

Fig. 9. – Overall landings and landings by species group of Algerian marine fisheries from 1999 to 2010: total landings (A), small pelagics (B), demersal fish (C), large pelagics (D), crustaceans (E) and molluscs (F).

DISCUSSION

On the Bou-Ismail Bay

The Bou-Ismail Bay Fishery, like most Mediterranean fisheries, is characterized by the dominance of small pelagic species. This is reflected in the high values recorded for the P/D index. The average for the ratio in this bay, a value of 9.9, is far higher than those calculated for other Mediterranean regions (Pennino and Bellido 2012, De Leiva Moreno et al. 2000). This could be because of the different spatial-temporal scale and the species taken into consideration when calculating the ratio. It seems useful to carry out micro-level studies for this type of indicator, because of the existence of specific characteristics for each fishery and the related ecosystems, which can be hidden on a larger scale. The P/D ratio is much more heavily influenced by landings of Clupeoid species, primarily sardines (*Sardina pilchardus*) and round sardinella (*Sardinella aurita*), which represent over 73% of overall catch. The P/D ratio is characterized by a very large initial

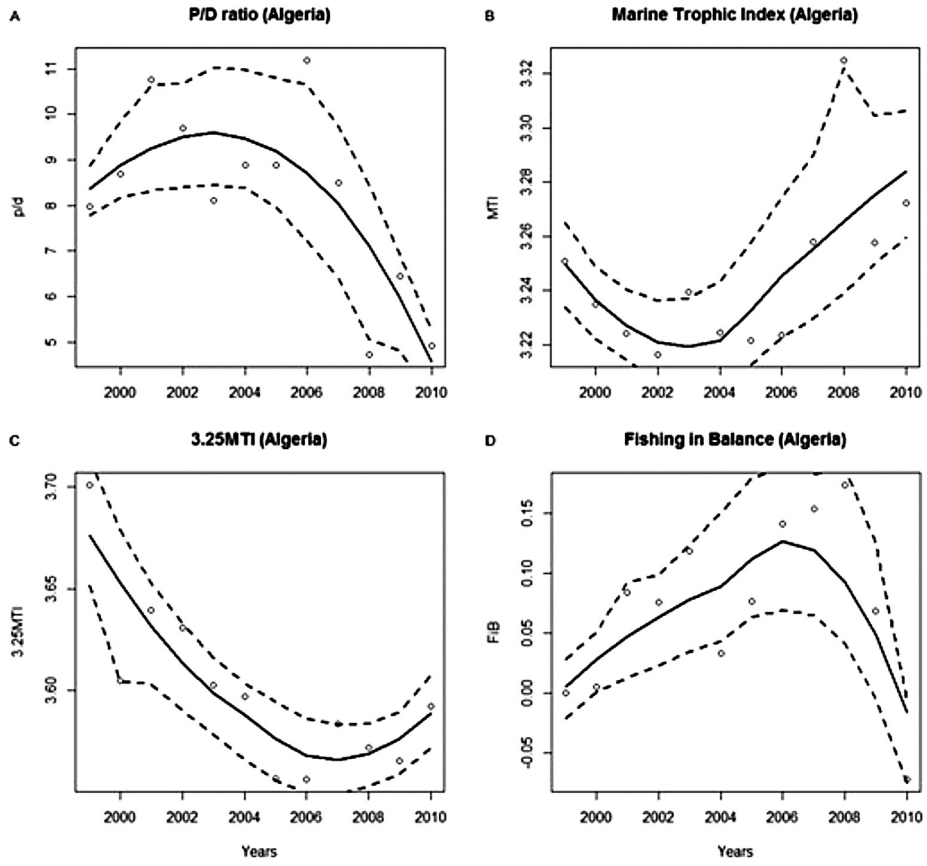

Fig. 10. – Trophic indicators for Algerian waters from 1999 to 2010.

decrease, then an increase over the very last years. The initial situation is due to the fall in small pelagic species and the increase in demersal fish within landings. The increasing scarcity of small pelagics, along with an increased fishing effort, suggests that these species are overexploited. In fact, despite rising primary production and nutrient input, which are favourable to these planktivorous species (Caddy 1993), their catch has fallen significantly, particularly in the case of sardine (*Sardina pilchardus*), whereas catches of the other small pelagic species (round sardinella, or *Sardinella aurita*) have increased in the latter years.

However, the increase in demersal fish catch is probably due to the increased fishing effort. In fact, over the last decade, several incentives funded by state subsidies have been introduced as part of the national development plan for fishing activities and aquaculture, and other programs have allowed for the growth and modernization of the fishing fleet. This increased fishing pressure is probably the reason behind the increased catches of these species, particularly pagellus (*Pagellus* spp.) and red mullet (*Mullus* spp.), in the first few years. However, the last four years of the series saw a fall in demersal fish catch, probably because of overexploitation (given the increased fishing effort) and/or eutrophication. In fact, the latter phenomenon, reflected in the increased primary production indicators (Chl-*a* and SST), preceded and probably caused the fall in demersal fish catch.

Eutrophication causes hypoxia situations, which have a negative effect on benthic species (Caddy 1993). Moreover, fairly high pollution levels have been observed in this zone (Houma 2009, PNUE 2005). These can also cause hypoxia. The start of a rise in the P/D ratio can indicate FDMW. This situation, as already observed in the Mediterranean (Pennino and Bellido 2012), indicates that the fishery increasingly targets small pelagic fish from the bottom levels of the trophic chain, such as round sardinella, for which catch was high during the latter years.

The ability to identify patterns consistent with FDMW has been discussed in considerable detail in the literature, along with the different conditions and data issues that could lead to similar patterns being identified that do not result from FDMW but from a range of fishery exploitations patterns throughout the food web (Essington et al. 2006, Litzow and Urban 2009, Branch et al. 2010 , Sethi et al. 2010). Each of these fishery exploitations patterns should be contrasted to offer alternative explanations to FDMW.

The lowest MTI values were recorded between 1999 and 2003, and correspond to high catches of Clupeidae of low TLs (an estimated 3.1 for sardines, and 3.13 for round sardinella). The high catches of these two species, accounting for over 72% of total landings, are the reason for the lowest recorded MTI figures. However, the increase in the MTI coincides with the lowest landings of sardines (*Sardina pilchardus*). The increased catches of the main demersal fish species from relatively high TLs during the first years, and their decreases during the last years, did not counterbalance the MTI trend. The predominance of small pelagics can

mask a possible effect of fishing on the trophic chain at medium and high TLs. Consequently, this indicator is unreliable for use in semi-enclosed seas, because of coastal phenomena such as eutrophication, which affects the abundance of small pelagic species and consequently impacts on their presence in landings. This can be confused with the effects of fishing (Caddy et al. 1998).

It therefore appears difficult to interpret the evolution of this index in a fishery greatly composed of small pelagics that are very vulnerable to environmental conditions. Consequently, the $^{3.25}$MTI (Pauly and Watson 2004) is an alternative to the MTI that reduces the influence of environmental conditions in the analysis of the effects of fishing on the trophic chain. The falling $^{3.25}$MTI, which indicates a decrease in the average TL of catch, suggests that the fishery is progressively targeting species from lower down in the trophic chain, probably because fish from upper TLs have been overexploited. The fall in the average TL of fish caught, combined with declining catches, where the fishing zone or gear usage has not changed, may indicate a collapse of the food chain (Pauly et al. 2001). The decrease, estimated at around 0.07 TLs for the 14 years studied, is close to that estimated by Pauly et al. (1998) at global level: around 0.1 per decade. However, it is far higher than those found in the Mediterranean by Pinnegar et al. (2003) (~0.07/36 years), which include aquaculture. However, these authors use the MTI indicator and study larger temporal series and scales. The FiB decreased throughout the whole period studied. This decrease was accompanied by an increase in the fishing effort, decreasing catch, and a fall in average TL ($^{3.25}$MTI). This indicates a serious problem: it suggests overexploitation on the scale of the ecosystem (Chassot 2005) and the exhaustion of inshore stocks (Bathal 2005), given the coastal nature of this fishery. The decrease in the FiB can be seen as the result of a modification in the trophic structure of the ecosystem, and of an alteration of its operation (Cury et al. 2005b, Pauly and Watson 2005). This is confirmed by the trend in the average TL of catches, which decreased by ~0.07 TL over the 14 years studied.

This trend towards a fall in the average TL of catch has not been accompanied by a rise in catch. Such a result would have justified a deliberate choice to displace efforts towards the bottom of the food chain: towards the more productive lower components of the trophic network. However, this did not happen. In fact, the FiB decreased during the period studied (Freire and Pauly 2010). Moreover, discards are not taken into account in the catch data, which may partly explain this trend in the FiB (Pauly and Watson 2005). This analysis of the FiB suggests that fishing in the Bou-Ismail Bay removes so much biomass from the ecosystem that its functioning is affected (Pauly and Watson 2005).

It is worth noting that despite recent criticisms of the FiB index as an indicator for proving that ecosystems are being degraded by fishing (Hornborg et al. 2013), we understand that it may still be a suitable indicator for showing the changes occurring in the ecosystem, but only if used complementarily with other indices.

On the Algerian waters and comparisons with the Bou-Ismail Bay

The comparison between the Bou-Ismail Bay and the national level is essential since certain phenomena appearing on a small scale can be hidden on a large scale (Bhathal 2005). The average annual landings of the Bou-Ismail bay are estimated at 6889 t/y. They represent nearly 5% of the national landings estimated at 126300 t/y, considering the same period between 1999 and 2010. However, the specific structure resembles and both them are characterized by the dominance of small pelagic species, mainly in the order of importance, sardine (*Sardina pilchardus*), sardinella (*Sardinella aurita*) and horse mackerel (*Trachurus* spp.).

The fall in the P/D ratio is caused by the decline in small pelagic catch despite the increased nominal fishing effort (with a near 70% rise in the number of sardine boats and seiners from 1999 to 2009 (http://www.mpeche.gov.dz) as a result of the sector development policy from 1999 onwards. This situation indicates the overexploitation on the Algerian coasts of small pelagic species, particularly sardines, for which catches are constantly falling (as in the Bou-Ismail Bay). The increased demersal fish catch at national level is due to the near 70% increase in the number of trawlers from 1999 to 2009, and an increase of around 100% in the number of small traders (http://www.mpeche.gov.dz). However, this increase can mask a situation of overexploitation for these species in the coastal zone, and maybe in some particular local sites hypoxia, as indicated for the Bou-Ismail Bay. In fact, new and more powerful trawlers, equipped with full modern navigational equipment, have been acquired with state subsidies with the aim of encouraging fishing in the high seas. The average TL of catch, including species from TL<3.25 (MTI), is highly influenced by landings of small pelagic species, as is the case in the Bou-Ismail Bay. It increases when catches of small pelagic species increase, and vice versa. As a result, a probable FDMW situation can be masked by these low-TL species, which are highly affected by environmental conditions. Consequently, we will use the $^{3.25}$MTI as the basis for our evaluation of the influence of fishing on the food chain in the ecosystem of the Algerian waters.

After eliminating from the calculation all species with a TL<3.25 ($^{3.25}$MTI), including small pelagics, detritivores and certain invertebrates, the average TL of catch decreases from 3.67 to 3.59 (~0.08TL/12 years). This decrease is very close to that of the Bou-Ismail Bay (~0.07/14 years), suggesting a situation of FDMW in the upper and middle TLs on the scale of the ecosystems exploited by fishing in the Algerian Mediterranean. An increase during the final period of the time series is seemingly due to the rise in catches of certain demersal species from high TLs, as a probable result of the exploitation of new zones by the new trawlers.

The FiB at national level exhibited positive values almost throughout the period studied, with an initial period of increase, followed by a decrease in the later years. The initial rise in the FiB indicates either an expansion of fishing or a "bottom-up" effect, via the

Table 3. – "Trade-off" table summarizing the trophic indicators studied, with landings, fleet information, and data on environmental variables for the Bou-Ismail Bay. ↓, falling trend; ↑, rising trend; ↑↓, increase followed by decrease; ↓↑, decrease followed by increase; ↔, Stable trend; +, parameter directly influencing the trend of the indicator.

Environmental variables	Landings	Fleet	*S. pilchardus*	*S. aurita*	*Trachurus* spp	*B. boops*	*Pagellus* spp	*Mullus* spp	*P. longirostris*	*X. gladius*	Total fleet	Trawlers	Sardine boats	Small traders			
↑	↑	↓	↓	↓↑	↓	↔	↑↓	↑↓	↓	↓	↑	↑	↑	↑			Conclusions
P/D	↓	+	+		+	+		+	+	+			+	+	+	+	- Overexploitation of *S. pilchardus,* - Overexploitation exacerbated by the hypoxia of demersal fish except *Boops boops.*
MTI	↑↓			+	+	+											Fishing down marine webs (FDMW) masked by small pelagic species landings
$^{3.25}$MTI).	↓						+	+	+	+	+	+					FDMW
FiB	↓			+	+	+	+	+	+	+	+	+	+	+	+	+	Ecologically unsustainable fishery
STATE OF THE ECOSYSTEM		ALERT ZONE															

increase of primary productivity (Pauly and Watson 2005). Both scenarios should be envisaged, though the "bottom-up" effect is more likely, since the average TL of catch is falling.

In fact, the expansion of fishing is perhaps caused by the exploitation of new zones by the new, powerful and well-equipped offshore trawlers. These were acquired as part of the plan to incentivize the fishing sector, the first being in 2003. This is reflected particularly by the increase in demersal fish landings. On the other hand, the Mediterranean Sea is a semi-enclosed sea, highly affected by nutrient inputs (Caddy and Garibaldi 2000). In fact this is the case of Algerian coasts, which are enriched not only by soil runoff, but also by nutrients from waters of Atlantic origin. It is likely that this source of nutrients may have favoured the increase in the biomass of small pelagic species decrease in the TL of catches.

Hence, we conclude that the results from Algerian waters are rather similar to those obtained at the level of the Bou-Ismail bay, particularly for the last years, and both show similar trends, suggesting an alteration of the mechanics of the underlying ecosystem, probably caused by overfishing (Daskalov 2002).

"Trade-off" table

Catch-based ecosystem indicators do not necessarily give a reliable representation of the ecosystem (Branch et al. 2010). However, they are useful for providing information about the methods of exploitation which could undoubtedly arise from a change in abundance or from a fishing strategy, as a consequence of the management policy or economic dynamic (Guénette and Gascuel 2012). However, the indicators should be combined and analysed together, in order to obtain an overall picture of the ecosystem dynamic. For example, interpreting a single indicator such as MTI could give misleading results, as demonstrated in this study, where it increased rather than decreasing.

The results of the indicators studied for the Bou-Ismail Bay, combined with the environmental variables and the available data on fisheries (such as landings and fleet data) are summarized in a "trade-off" table (Table 3), to facilitate their interpretation and create a "toolbox" for implementing an EAFM. The decrease in the FiB, accompanied by a fall in the TL of catch ($^{3.25}$MTI) and in the P/D, allows the Bou-Ismail Bay's ecosystem to be classified as an alert zone signifying unsustainable management of this zone. Consequently, this fishery requires immediate planning measures, such as a reduced fishing effort and stronger controls to avoid stock collapse.

This "trade-off" table remains purely indicative. It requires completion by other results concerning fisheries in other regions of the Algerian coast, in order to permit comparisons and probably define other zones that could serve as toolboxes for management needs. This could offer an alternative to the cumbersome model requiring large amounts of data on recruitment, size-weight relationships, and other unavailable and difficult-to-obtain biological data.

In conclusion, the use of trophic indicators in the evaluation of ecosystems subject to fishing offers an alternative to complex models requiring huge amounts of data which are not always available. This is particularly the case is studies of Algerian fisheries (for which data are often scarce). Consequently, we wish

to encourage other studies of this kind, evaluating all fisheries at national level using longer historical series and locally-established TLs distributed according to size, in order to obtain the best possible results.

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